Use of UUVs to Evaluate and Improve Model Performance within a Tidally-Dominated Bay

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LONG-TERM GOALS

We propose to continue our work coupling Unmanned Underwater Vehicle (UUV) observations with a 3D hydrodynamic model (Delft3d-FLOW) to investigate circulation in a tidally dominated system. While these areas have traditionally been difficult to sample, UUVs with advanced sensor technology afford the opportunity to systematically study the dynamic components of these systems. Highly resolved measurements of circulation patterns, in water components, bottom topography and characterization will be coupled with the modeling effort. This combination will allow UUV guidance and improve model performance. It is hoped that the integration of mobile systems for localized modeling will be a ‘system’ that is portable to other systems to help advance our understanding of circulation patterns and mechanisms for change in bottom topography and morphology.

OBJECTIVES

The objective of this work is to improve model-UUV integration towards improved model performance. The primary goal of this study is to compare predictions of plume advection and dispersion using a 3D hydrodynamic model (Delft3d-FLOW) with actual field measurements. Initial experiments with the uncalibrated model were conducted in order to predict plume propagation based on the best available data. Field experiments were subsequently carried out by releasing rhodamine dye on the surface of Sequim Bay (Sequim, Washington) from an anchored vessel in 2006. Concurrently collected data from the experiment include temperature, salinity and dye concentration collected from surface vessels. A REMUS autonomous underwater vehicle was used to measure current velocity and dye concentration at varying depths, as well as to acquire additional bathymetric information. The objective of this work was to evaluate the model performance with and without UUV observations in this dynamic system.

APPROACH

Model Configuration. A three-dimensional circulation and transport model was developed using Delft3D to predict the advective transport from a point release in Sequim Bay, Washington. Tidal, wind-driven and density-driven circulation were accounted for in the model. The effects of bathymetry, earth's rotation and bed stress are also included. The model is based on the continuity equation and horizontal momentum equation and uses a turbulence closure submodel to adjust mixing rates as function of flow conditions. The model domain is represented by a orthogonal curvilinear mesh in the horizontal and a terrain following ($\sigma-$) coordinate system in the vertical. The model numerics are fully documented in WL Delft Hydraulics (2003) and it has been used to conduct various modeling studies (*i.e.* Hesselink *et al.* 2003; Bielecka and Kazmierski 2003). The model mesh was developed based the best bathymetry information available that provided comprehensive coverage within the bay and the area of the Strait of Juan DeFuca just outside of Sequim Bay. This was a publicly available gridded 10m resolution dataset (Finlayson 2005), which was transformed to a Cartesian coordinate system (UTM Zone 10N, WGS84). The shoreline evident at the spatial scale of this data set was used to represent the closed boundary of the model. A model mesh was extended to distant open boundaries so that circulations near the area of interest (the Sequim Bay mouth) were driven by model physics rather than the artificiality introduced in proximity to these boundaries. The tidal elevation conditions along all open boundaries were set to available tidal predictions from Xtide (Flater 2006) for Whidbey Island (on the northeast corner of the model domain), Dungeness Spit (on the west boundary) and Port Townsend (on the east boundary) so that the model could be run in a predictive mode. This mesh had 108×132 horizontal computation cells, and the water column was subdivided into ten layers. A finer resolution mesh (187×145 horizontal cells) was nested within the coarse mesh in order to focus on the region near the RWT release location. While the number of vertical layers remained the same for both meshes, the vertical resolution differed. The circulation within the finer resolution model was driven by flow (tidal elevations or currents) provided by the coarse model results, archived every five minutes over the period of interest.

Environmental Data Collected. Environmental data was collected during July/August, 2006 from Sequim Bay, WA. Tidal elevation and wind speed were collected during the rhodamine dye (RWT) release. A REMUS UUV was deployed simultaneous to the release in the area predicted by the uncalibrated model run. See Moline *et al.* (2005, 2007) for description of vehicle used and study area. The UUV was able to sample the plume at a fixed depth and clearly resolve the boundaries of the plume using a rhodamine fluorometer mounted to the vehicle. The modeled tidal elevations agree quite well with those predicted at the mouth of Sequim Bay. Current speed in the channel was measured by a bottom-mounted ADCP (1200 kHz RD Instruments). Comparisons of modeled current profiles are reasonable, with better agreement on ebb tide than flood tide indicating that tidal current asymmetry is not fully captured by the model.

WORK COMPLETED

An initial meeting was held at PNNL in Sequim, WA on October 18-22, 2007 to develop an analysis strategy and timetable for publication of the work. Since this initial meeting, we continued analysis and data synthesis in a number of specific areas for publication in a peer-reviewed journal. These include evaluation of the general model performance of tidal currents by comparison to ADCP measurements, evaluation of model performance based on in situ dye measurements made by UUV, use of high spatial resolution of the UUV to make direct performance metrics of frontal locations quantifiable, evaluate model performance of characterizing the dye plume with updated bathymetry measured by the UUV, and finally we published these results (Hibler et al, 2008). The work was also presented at the AGU meeting in San Francisco in December, 2007. (Maxwell et al, 2008).

RESULTS

Re-analysis of the AUV and model intercomparisons with AUV and ADCP data for Sequim Bay and reporting. ONR's Coastal Environmental Effects (N000-14-06-2-0105) program developed observational datasets that were used in the present study to improve the model performance. Model and data comparisons were made between UUV water quality measurements and well as with ADCP records in Sequim Bay, WA. UUV bathymetry surveys were also used to improve the model configuration. As part of this program, Hibler et al (2008) showed the improved predictive capability for the model plume effort under different stage of model development. The model was first used without data input to evaluate in a general sense where the RWT dye would move for planning of the UUV missions. The model then incorporated observational data for comparison and evaluation. Figure 1 illustrates the sequencial improvement of the model as UUV data is added with winds (intermediate) and CTD data with a no-slip condition is added (final). This shows that the model performs very well during the moderate dilution phase at estimation of the timespace location of the plume centerline while not capturing peak concentrations as well. This finding is consistent with that reported by *Stacey et al.* [2000], and understandable given the nature of the Eulerian model.

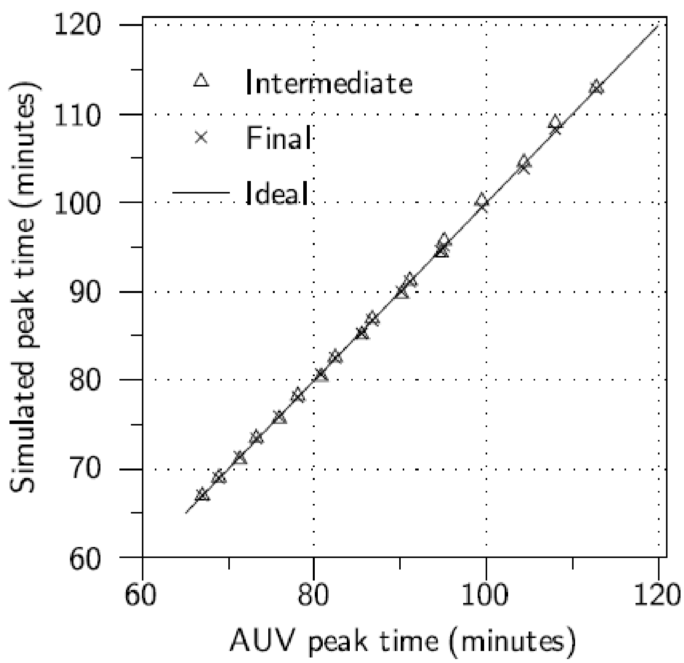

Figure 1. Comparison of UUV data and modeled data of the timing for peak Rhodamine dye detection during the plume prediction experiement. The UUV was programed to sample in and out of the plume field based on an initial model run without data input. This data illustrates that the model provided good guidance for the UUV to map the phenomena and that the model performed well in predicting the plume track.

IMPACT/APPLICATIONS

This modeling effort has provided the first, physically based quantification of the complex flows around the mouth of Sequim Bay that account for Middle Ground, an intertidal shoal. The presence of this shoal provides a significant control on the division of flow in the northern portion of bay. The complex circulation in this portion of the bay was found to greatly influence the RWT transport. Model currents compare well to the ADCP data within the mouth of Sequim Bay. The model does not reproduce the high frequency oscillations in flow found by the ADCP. However, the tidal velocities match well, on average, in terms of matching timing and amplitude of current peaks. Analysis of the HSI plume delineations indicates that there are finer scale features evident in the plume that the model has not resolved. This is due to a variety of causes. The model resolution is O(10 m) and the discernible features have scales as small as a few meters. Bathymetry details and the shore line are at subgrid scales, and features outside of the surveyed area are likely influencing plume behavior. Although measured winds are applied to the intermediate and final model applications, the representativeness of applied wind field and its spatial variability are not assessed in this study. In spite of these issues and their limitations, the model performance for making plume trajectory estimates was found to be good. The planning phase model study was important in assessing the probable trajectory of the plume, particularly given the complex flow patterns near Middle Ground. Streamlines based on this initial simulation provided a guide to development of the UUV track. However, results of the preliminary simulation were not favorable when compared with field measurements. During the intermediate phase of the model effort, it was found that bathymetric variability had a significant effect on the accuracy of Delft3DFLOW simulations of the near to midfield plume behavior, which is not surprising. Finally, incorporating the effects of stratification was essential in this environment. Integration with UUV RWT fluorometer data was found to be essential for improving the model. Comparisons of plume delineations derived from the modeling study compare well with those determined from the fluorometer during the active release period. The magnitude of the estimated concentration is systematically lower than measured values. The model was assessed to provide skillful transport estimates focused on active releases and for plume delineation only. Improved model assessments would likely be possible with the benefit of additional release tests.

RELATED PROJECTS

This project originated from work done in ONR’s Coastal Environmental Effects (N00014-06-2-0105) program. A continuing effort derived from this project is taking place along the Tijuana River estuary mouth to evaluate sources and trajectories of tagged water masses. Again, this project will use the combination of UUV measurements with the DELFT model (N00014-08-1-0508).

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PUBLICATIONS

Hibler LF, AR Maxwell, LM Miller, NP Kohn, DL Woodruff, M. J. Montes, J. H. Bowles and M. A. Moline. (2008). Improved fine scale transport model performance using AUV and HSI feedback in a tidally dominated system. J. Geophys. Res., 113, C08036, doi:10.1029/2008JC004739. [published, refereed]

HONORS/AWARDS/PRIZES

Mark A. Moline, named lifetime Fellow of the California Council on Science and Technology